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CREATING A SUBTERRANEAN RIVER AND SUPPLYING A METROPOLIS WITH MOUNTAIN WATER

BY

J. BERNARD WALKER AND A. RUSSELL BOND

FROM THE SMITHSONIAN REPORT FOR 1913, PAGES 709-722
(WITH PLATES 1-11)

(PUBLICATION 2309)

WASHINGTON
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CREATING A SUBTERRANEAN RIVER AND SUPPLYING A METROPOLIS WITH MOUNTAIN WATER.[1]

By J. Bernard Walker and A. Russell Bond.

[With 11 plates.]

I. CREATING A SUBTERRANEAN RIVER 90 MILES IN LENGTH.

By J. Bernard Walker.

PHENOMENAL GROWTH OF NEW YORK.

Greater New York is adding to its population at the rate of 140,000 people per year—an increase which is absolutely without precedent or parallel in the growth of the world's great cities. Such an increase as this renders enormously difficult the problems of housing, food supply, transportation, and proper hygiene. For many years past, and long before the rate of increase had reached its present proportions, the city authorities have been at their wits' end in endeavoring to enlarge the various facilities of the city so as to keep pace with the demands of its ever-growing population.

THE PERIL OF WATER FAMINE.

With the exception of rapid transit, there is no problem of the city's need which has proved more serious, more pressing or more difficult, at least in recent years, than that of providing an adequate supply of pure drinking water. At frequent intervals the city has been threatened by that justly dreaded terror, a water famine—justly dreaded, because a shortage, to say nothing of a total failure, of water might mean an outbreak of pestilence, to say nothing of the loss and inconvenience occasioned by the shutting down of the various factories and smaller industries which a shortage of the water supply would necessitate.

It is not so very many months since the whole city was watching, with a very anxious eye, the steady fall of the water levels in the various reservoirs of the Croton watersheds; for a season of drought, extending far into the winter, had served to bring the hitherto remote peril close to its very doors.

In view of the rapid growth of the city, it was evident at the outset that any adequate scheme for increasing the water supply must be made upon the broadest possible scale; and that it should make provision, not only for the immediate needs of the city, but for those of many a decade to come. This has been done by the board of water supply; and it is the purpose of this and the following article to show that the project of bringing the Catskill Mountain water to New York has been considered on such adequately comprehensive lines that the possibility of any shortage of water in this great city has been removed into the very far future.

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[1] Reprinted by permission from Scientific American, New York, vol. 108, No. 9, Mar. 1, 1913.

On May 14, 1906, the State water supply commission approved of the application of the board of water supply of this city for obtaining a daily supply of 500,000,000 gallons of water from the Esopus, Rondout, Schoharie, and Catskill Creeks in the Catskill Mountains, at an estimated cost of $161,867,000. In 1910 a plan for the distribution of the water throughout Manhattan, Queens, and the Bronx by a deep-pressure tunnel was approved by the board of estimate and apportionment. The additional cost of this scheme is $15,000,000.

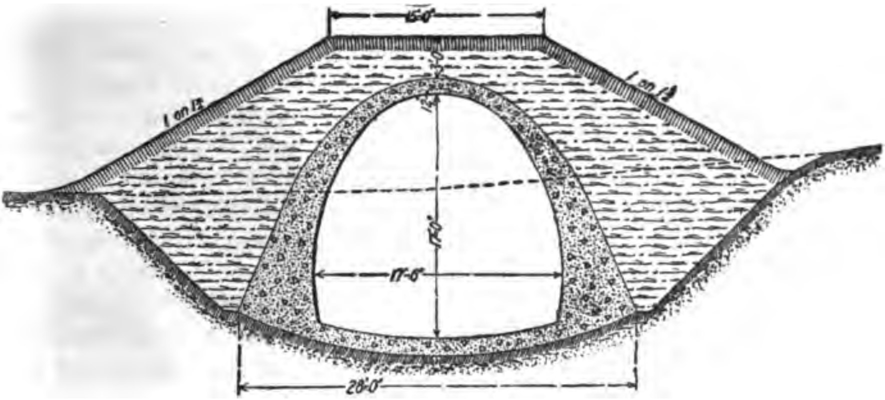
THE NEW SCHEME OF WATER SUPPLY.

The new supply of water, of the finest mountain quality, is to be taken from four watersheds, having a total area of nearly 900 square miles. The total estimated capacity of these four gathering grounds is, even in a series of unusually dry years, equal to supplying 770,000,000 gallons daily. Reservoirs will be built, as they are required, in each of these basins, and they will be connected by aqueducts. For the present, the Esopus watershed only is being developed. In a series of dry years this watershed can furnish a daily supply of only 250,000,000 gallons; but the aqueduct leading to the city is being built of double that capacity or 500,000,000 gallons daily. The first contract for construction was let at the close of 1906. In 1907 to 1908 about 5 per cent of the work was completed from Ashokan reservoir in the Esopus watershed to Croton Lake. By the end of 1909, 22 per cent was done, 60 per cent at the close of 1910, 78 per cent by 1911, and at the present time about 95 per cent of the work is done. The delivery of water into the Croton Reservoir, which will be possible this year, will prevent any possibility of water famine during the completion of the new aqueduct to New York.

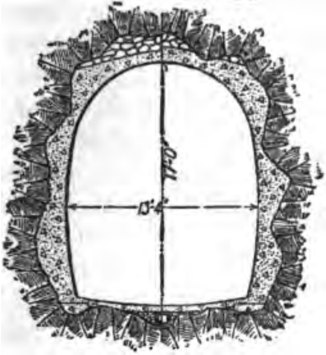
The system under construction and now nearing completion consists of a large reservoir in the Esopus Basin, an underground aqueduct 17 feet in diameter by which the water is led for 64 miles to another large basin, the Kensico Reservoir, which will serve for emergency storage; a third reservoir situated about 15 miles south of Kensico and just over the New York city line, known as the Hill View Reservoir, which will equalize the difference between the use of water in the city, which, of course, varies from hour to hour and from day to day, and the steady flow coming in from the aqueduct. Between Hill View and the city the system consists of a deep circular, high-pressure tunnel, through which the water will be led beneath Manhattan, to be distributed by surface mains throughout that city, and also throughout the other districts of Greater New York.

THE ASHOKAN RESERVOIR.

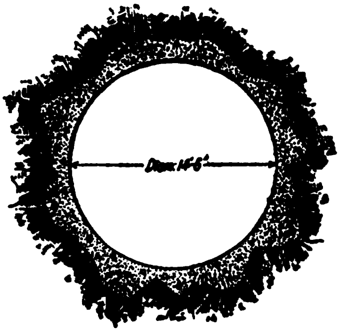
The great Ashokan Reservoir is situated about 14 miles west of Kingston, on the Hudson River. Its cost is $18,000,000, and it will hold sufficient water to cover the whole of Manhattan Island to a depth of 28 feet. The water is impounded by the Olive Bridge Dam, which is built across Esopus Creek, and also by the Beaver Kill and the Hurley dikes, which have been built across streams and gaps lying between the hills which surround the reservoir. By the 1st of January, this year, 73 per cent of this work was done. The dam is a masonry structure 190 feet in thickness at the base, and 23 feet thick at the top. The surface of the water when the reservoir is full is 590 feet above tide level. The total length of the main dam



CUT AND COVER AQUEDUCT



GRADE TUNNEL



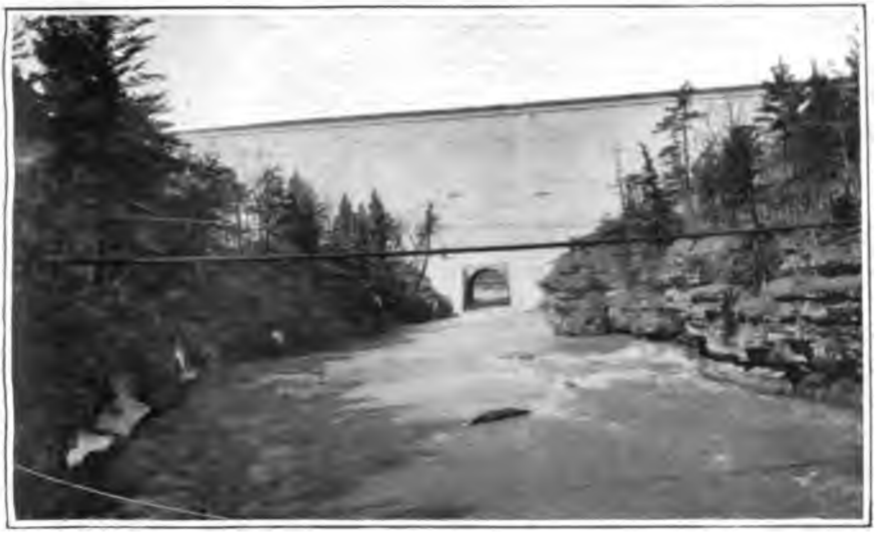
PRESSURE TUNNEL

is 4,650 feet, and the maximum depth of the water is 190 feet. The area of the water surface is 12.8 square miles, and in preparing the bottom it was necessary to remove seven villages, with a total population of 2,000. Forty miles of highway and 10 bridges had to be built. In the construction of the dam and dikes it was necessary to excavate nearly 3,000,000 cubic yards of material, and 8,000,000 cubic yards of embankment and nearly 1,000,000 cubic yards of masonry had to be put in place. The maximum number of men employed on the job was 3,000.

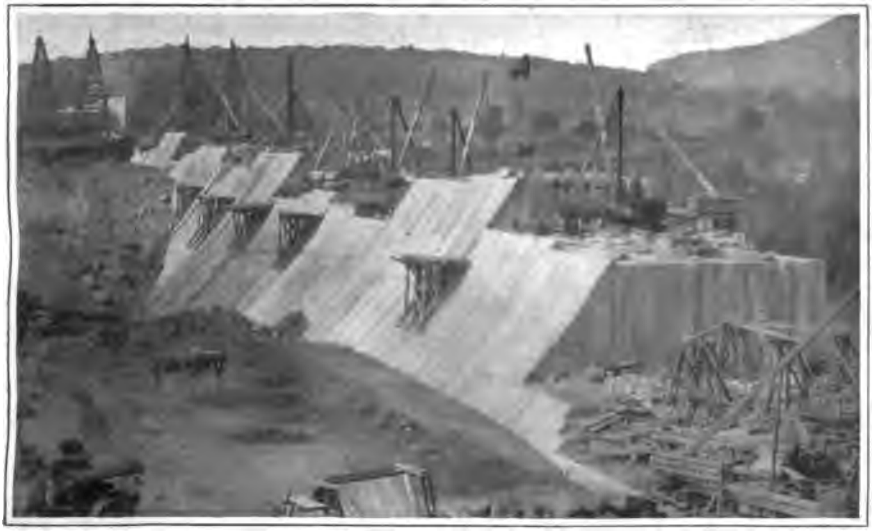
THE 92-MILE AQUEDUCT.

The water is conducted from Ashokan Reservoir as a huge underground artificial river. The aqueduct is 92 miles in length from Ashokan to the northern city line, and it should be explained that it is built on a gentle grade, and that the water flows through this at a slow and fairly constant speed. The aqueduct contains four distinct types: The cut-and-cover, the grade tunnel, the pressure tunnel, and the steel-pipe syphon. The cut-and-cover type, which is used on 55 miles of the aqueduct, is of a horseshoe shape and measures 17 feet high by 17 feet 6 inches wide, inside measurements. It is built of concrete, and on completion it is covered in with an earth embankment. This type is used wherever the nature of the ground and the elevation allow. Where the aqueduct intersects hills or mountains it is driven through them in tunnel at the standard grade. There are 24 of these tunnels, aggregating 14 miles in length. They are horseshoe in shape, 17 feet high by 13 feet 4 inches wide, and they are lined with concrete. When the line of the aqueduct encountered deep and broad valleys, they were crossed by two methods: If suitable rock were present, circular tunnels were driven deep within this rock and lined with concrete. There are 7 of these pressure tunnels of a total length of 17 miles. Their internal diameter is 14 feet, and at each end of each tunnel a vertical shaft connects the tunnel with the grade tunnel above. If the bottom of the valley did not offer suitable rock for a rock tunnel, or if there were other prohibitive reasons, steel siphons were used. These are 9 feet and 11 feet in diameter. They are lined with 2 inches of cement mortar and are imbedded in concrete and covered with an earth embankment. There are 14 of these pipe siphons in a total length of 6 miles. At present one pipe suffices to carry the water. Ultimately three will be required for each siphon.

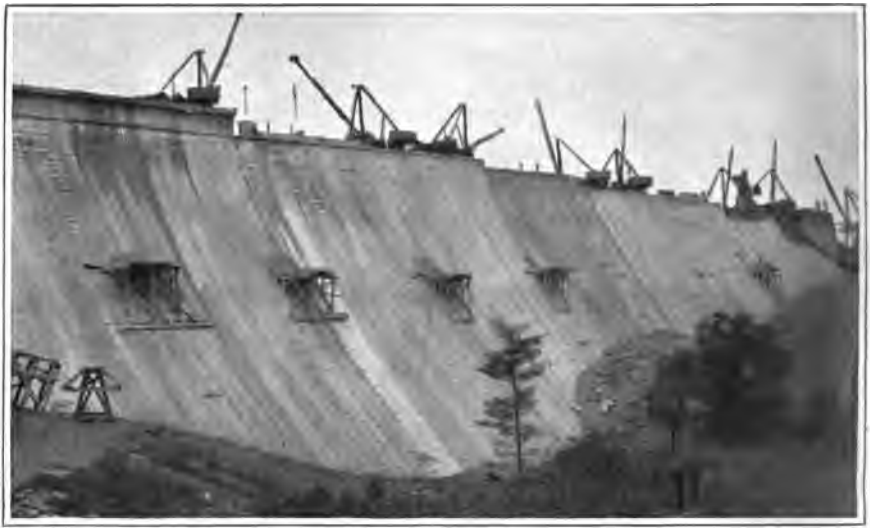
Of the many siphons constructed, by far the most interesting and difficult is that which has been completed beneath the Hudson River. The preliminary borings made from scows in the river showed that great depths would have to be reached before rock sufficiently solid and free from seams was encountered to withstand the enormous hydraulic pressure of the water in the tunnel. After failing to



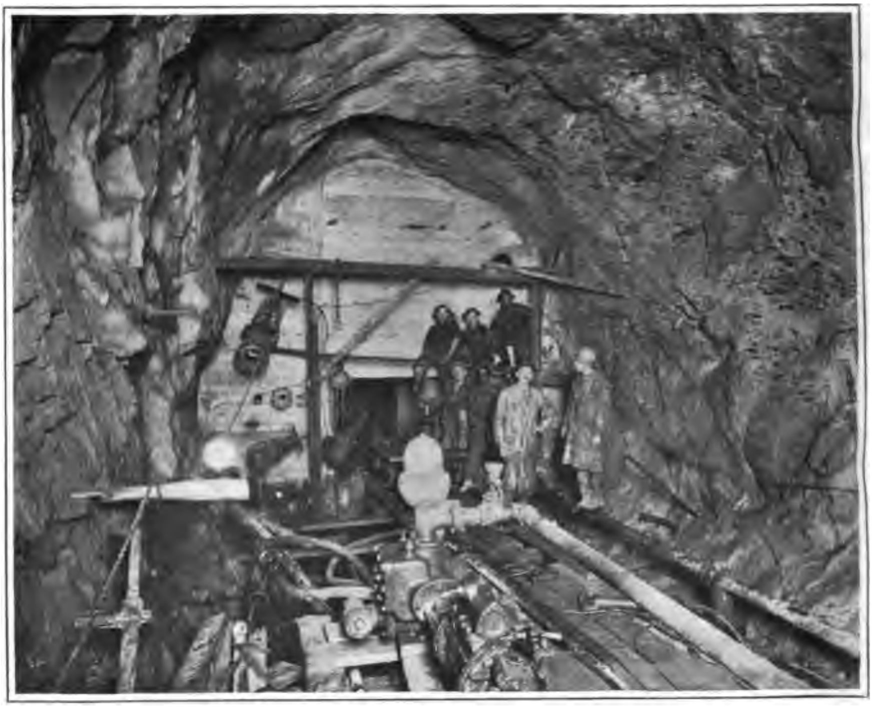
OLIVE BRIDGE DAM. ESOPUS CREEK FLOWING THROUGH TEMPORARY TUNNEL.



BUILDING OLIVE BRIDGE DAM TO FORM THE ASHOKAN RESERVOIR.

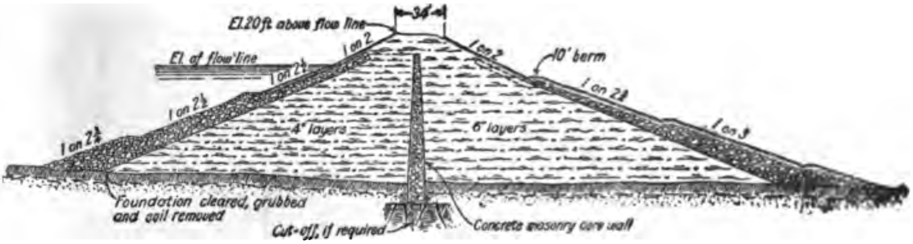


THE OLIVE BRIDGE DAM, 4,650 FEET LONG, 220 FEET HIGH.

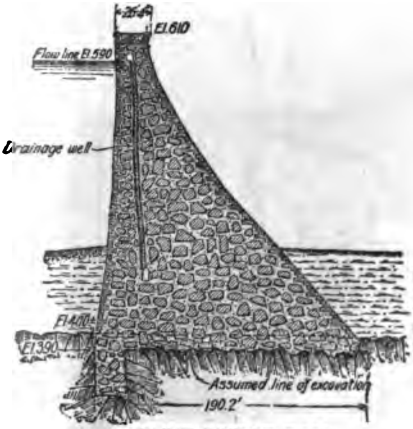


IN THE HUDSON RIVER SIPHON, 1,100 FEET BELOW THE RIVER.

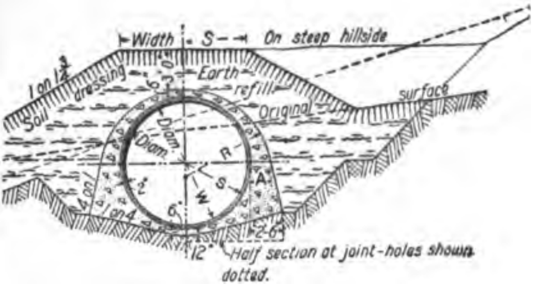
reach rock by the scow drills, two series of inclined borings were made from each shore, one pair intercepting at about 900 feet depth and the other at about 1,500 feet. Both showed satisfactory rock; and accordingly a shaft was sunk on each shore to a depth of approximately 1,100 feet, and then a horizontal tunnel was driven connecting the two. It is of interest to note that because of the enormous head, which must be measured from the flow line far above the river surface, the pressure in the horizontal tunnel reaches over 40 tons per square foot. (550 lbs. sq. in.)



TYPICAL SECTION OF DIKE



OLIVE BRIDGE DAM
MAXIMUM MASONRY SECTION

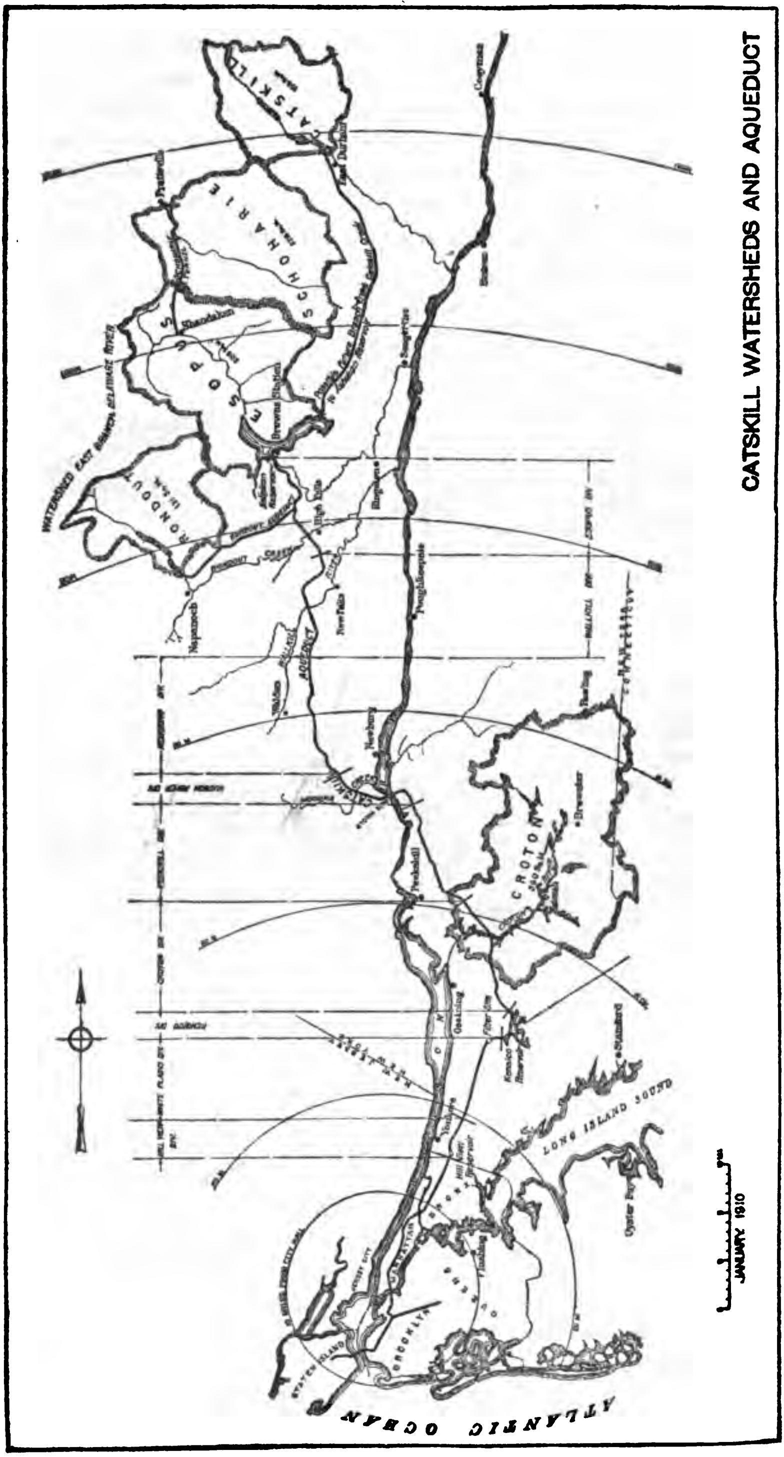


STEEL PIPE SIPHON

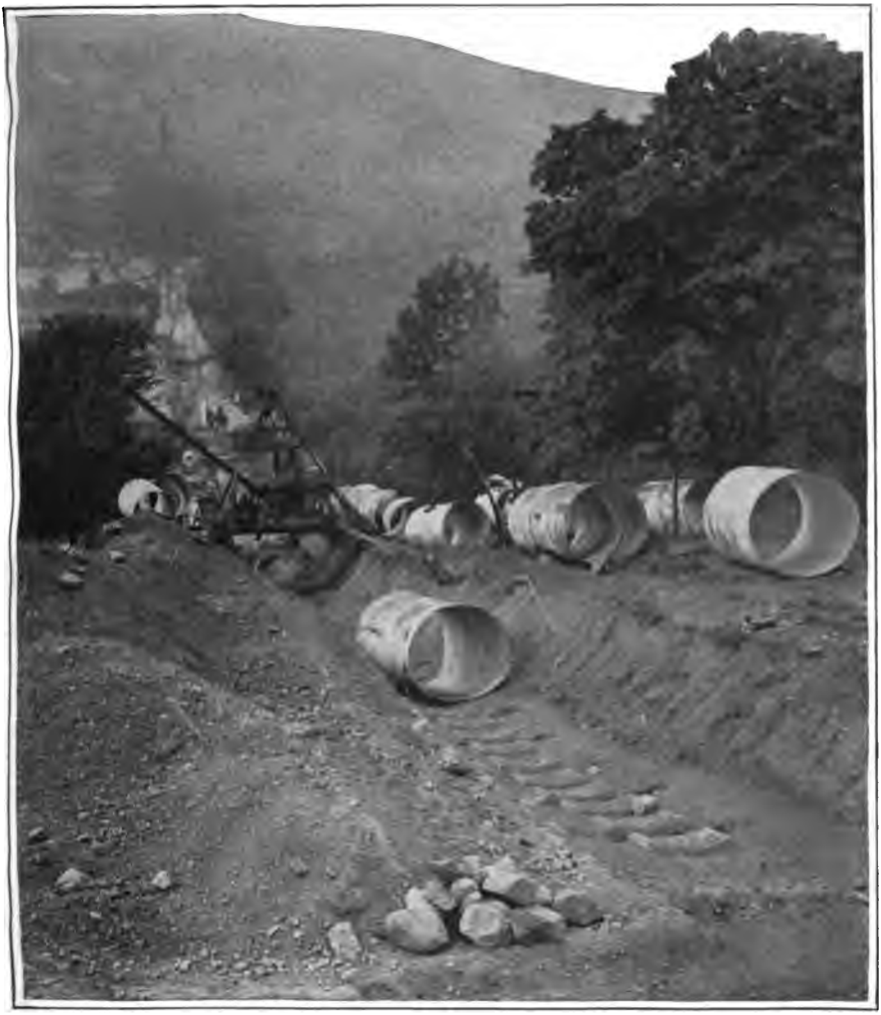
KENSICO RESERVOIR.

Next to Ashokan the most important basin is the Kensico reservoir, which lies east of the Hudson, and is situated 30 miles north of the city hall. It will hold sufficient of the Catskill water to supply the city for several months. Its purpose is to act as an emergency storage reservoir, so that if it is necessary, on account of accident, to interrupt the flow in the 77 miles of aqueduct between Kensico and Ashokan, this can be done without interrupting the city supply. The cost of this work is $8,500,000.

The reservoir will be formed by a huge masonry dam across the valley of the Bronx River. The surface of the water will be at an



MAP SHOWING CATSKILL AND CROTON WATERSHEDS AND THE AQUEDUCT.



PLACING THE 9½ FOOT STEEL PIPES—FOUNDRY BROOK SIPHON.

DRIVEWAY ALONG CREST OF OLIVE BRIDGE DAM.

This will form part of a system of new highways.

ASHOKAN RESERVOIR—UPPER GATE CHAMBER.

Through this chamber the flow of water to the aqueduct will be regulated.

elevation of 355 feet above mean sea level, and will cover 2,218 acres. It will contain, when full, about 40,000,000,000 gallons, of which 29,000,000,000 gallons, or 60 days' continuous supply at 500,000,000 gallons daily, will be available. The main dam will be 1,843 feet long; the total height will be 300 feet; it will be 230 feet thick at the base, and 28 feet thick at the top. The average depth of the reservoir will be 100 feet, and its maximum depth at the wall of the dam will be 155 feet. An interesting feature of the construction is that the entire dam will be divided into sections by transverse expansion joints, which will be placed about 80 feet apart longitudinally. On one side they will be faced with concrete blocks, forming a series of vertical tongues and grooves, against which the masonry of the other side will be built. Near the up-stream face will be a copper strip, which will cover the expansion joints and act as a water stop, the strips continuing from the bottom to the top of the dam. In order to catch any water that may seep through from the up-stream side, diagonal wells will be built 15 feet apart, measured longitudinally. They will be formed of porous concrete blocks. They will reach from the top of the dam to a longitudinal inspection gallery at about the level of the reservoir bottom, which will in its turn be connected with a transverse drainage gallery, which will lead to the downstream base of the dam. This will entirely prevent any seepage through the wall, and will avoid that discoloration which is liable to mar the architectural beauty of structures of this kind.

AERATION AND FILTRATION.

At both the Ashokan and Kensico reservoirs aerators will be built, each of which will be capable of passing and treating all the water which will flow in the aqueduct. The aerator is a large rectangular basin, 500 feet by 250 feet, containing about 1,800 nozzles, through which jets of water will be thrown into the air. The nozzles will be of such form that the water will be divided into a fine spray, and this will permit of a thorough admixture with the oxygen of the air and the removal of gases and matters which would cause taste and odors. For the present no provision will be made for filtrating the Catskill water, but provision has been made for a filtration plant by the purchase of 350 acres of land near Tarrytown, adjacent to the aqueduct.

HILL VIEW RESERVOIR.

From Kensico the water will flow to the Hill View reservoir, which will serve to equalize the difference between the amount of water used in the city and the amount of water flowing in the aqueduct. Also it will furnish a great quantity of water should there be an immediate demand, such as occurs during a great conflagration. Its capacity will be 900,000,000 gallons. The reservoir is divided into two basins, so that one may be used while the other is being inspected for repairs. The aqueduct is carried within the wall which divides the two basins, and the aqueduct water can be passed through the reservoir and delivered directly into the city tunnel.

Our thanks are due to Mr. Alfred D. Flinn, department engineer of the board of water supply, for courtesies extended during the preparation of this article.

II. SUPPLYING A METROPOLIS WITH MOUNTAIN WATER.

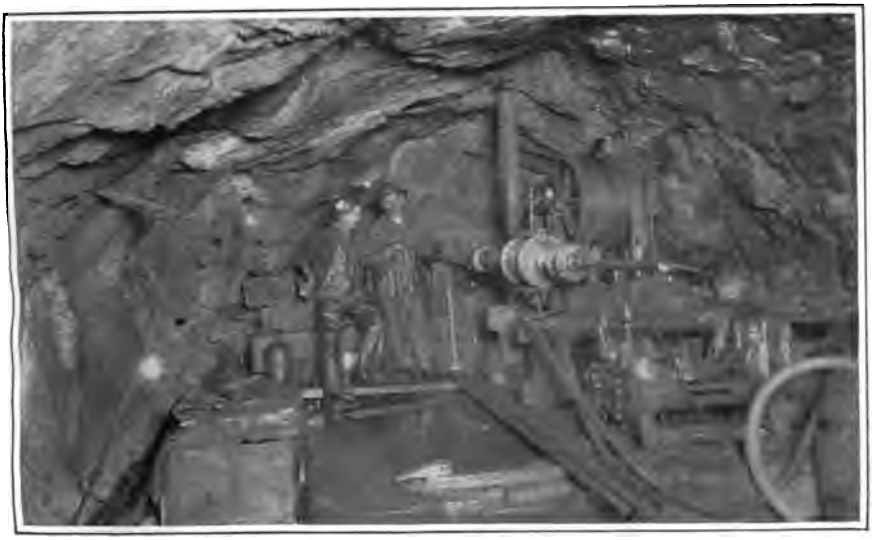
By A. Russell Bond.

HOW MINING OPERATIONS ARE BEING CARRIED ON THROUGH THE HEART OF NEW YORK.

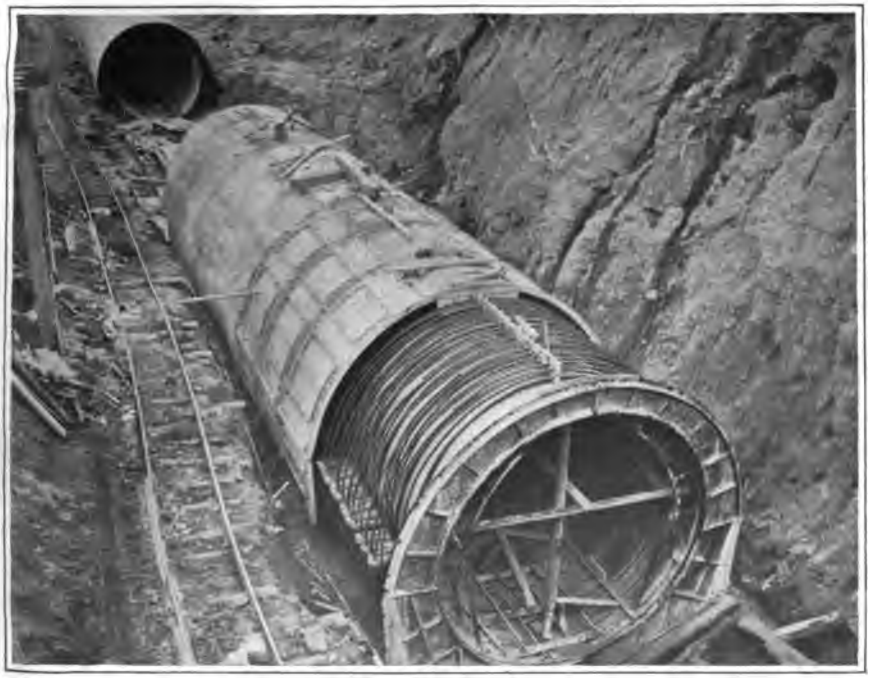
The preceding pages tell how the new aqueduct is being constructed from the Catskill Mountains down to the New York City line, where, at the Hill View Reservoir, the waters will pause before taking their plunge into the heart of the city.

The problem of admitting so large a flood into the metropolis is no small one, particularly when the chief demand for the water will come from those sections of Greater New York which lie many miles away. For the present, at least, little if any of the Catskill water will be used in Manhattan and The Bronx, but most of it will be consumed by the boroughs of Brooklyn, Queens, and Richmond. The water-waste campaign which has been carried on for the past few years has so far reduced the consumption of water that the Croton system, which can furnish steadily 350,000,000 gallons of water per day, can easily take care of the immediate wants of Manhattan and The Bronx as well as the demand from these two boroughs for many years to come. It is not likely that the population in Manhattan will increase much, unless it undergoes a marked vertical growth, for now there are practically no more vacant lots to be built upon. So that in estimating the future demands upon the Croton system, we must consider chiefly the growth of population in The Bronx. In the other three boroughs of the city, however, there is a present demand for water, and the probability of large increases in population in coming years.

To conduct the Catskill water into Brooklyn and Queens, it was decided to build a trunk line so far beneath the surface that there would always be 150 feet of good, solid rock for the roof of the tunnel, and provide a course for a subterranean river which could be tapped as needed for the city's supply, and which at the same time would be so completely buried that it would never menace the safety

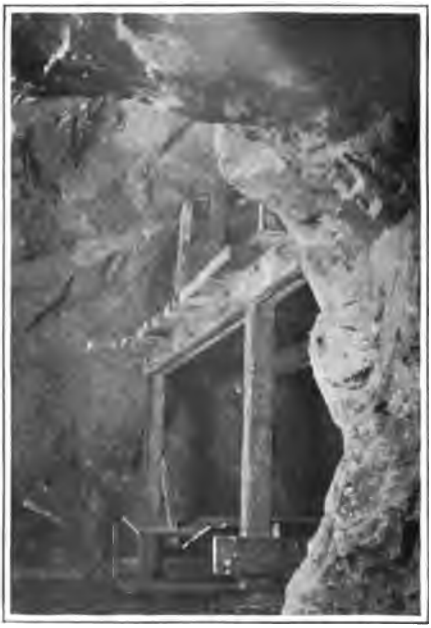


DIAMOND DRILL BORING HORIZONTAL HOLE 1,100 FEET BELOW HUDSON RIVER.



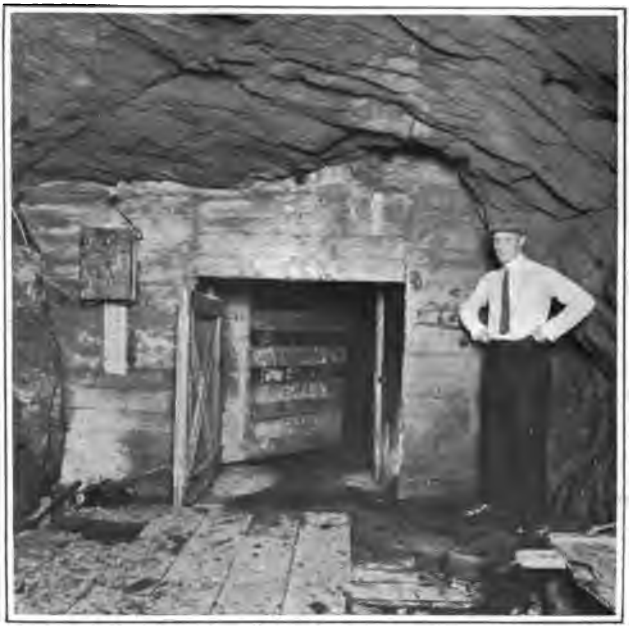
CONSTRUCTING A STEEL AND CONCRETE SECTION OF AQUEDUCT.

This section consists of a steel pipe, lined internally with 2 inches of cement mortar, and embedded in reinforced concrete.



DYNAMITE CHAMBER.

Note the roof over the shelves.



MAGAZINE DOOR, WHICH CLOSES AUTOMATICALLY IN CASE OF EXPLOSION.

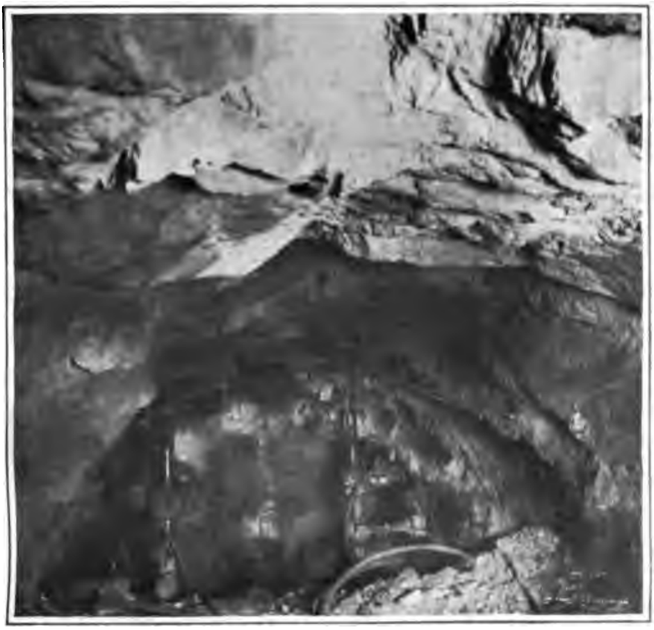
of structures above it. When the tunnel is completed, it will be one of the most durable pieces of work ever constructed by man; for practically nothing but an earthquake can destroy it, and even this possibility is very remote, for the rock underlying New York is of very early formation, and not at all liable to seismic disturbance. And so the city tunnel of the Catskill aqueduct is being bored through the rock on an average of 200 to 250 feet below the surface, except in places where the nature of the rock is of such a character as to call for a much greater depth.

The first dip takes place just above the Harlem River, where the tunnel drops down to 362 feet below the ground level. Then it runs practically horizontally until it passes the dip in the rock under One hundred and twenty-fifth street. Thence it rises again, and maintains a practically constant level of 200 feet under the city until it arrives at the ancient bed of the East River. A glance at the map of New York City will show that the East River makes a decided turn about the lower east side or "heel" of Manhattan. In preglacial times the East River had no elbow in its course, but ran directly across the heel of Manhattan, and it wore away the rock in its bed to considerable depths. However, the large deposits of earth and rock carried by the glaciers caused the river to be pushed eastward, out of its normal channel and over the solid rock beyond. When borings were made for the aqueduct through this section of the city, it was found necessary to lay it at a depth of about 750 feet below the surface. As indicated in the drawing on page 721, much of the rock through this section is decayed and unfit to form the walls of a high-pressure aqueduct which is being built to last for all time. The present channel of the East River, on the other hand, passes over solid rock, and is comparatively shallow. Seven hundred and fifty feet is an enormous depth, second only to the great siphon under the Hudson River, which is 1,114 feet below the river surface. It so happens that the deepest shaft ever sunk in New York City equals the height of the tallest building in the world. To illustrate this enormous depth, our artist has taken the liberty of building the Woolworth Building topsy-turvy—that is, from the ground down—at the Clinton Street shaft at the west bank of the East River. Enormous as is the building, yet it barely reaches the aqueduct at this point. Evidently there will be plenty of cellar room over the tunnel; and yet it is worth noting, the aqueduct follows the street lines so as not to trespass on private property.

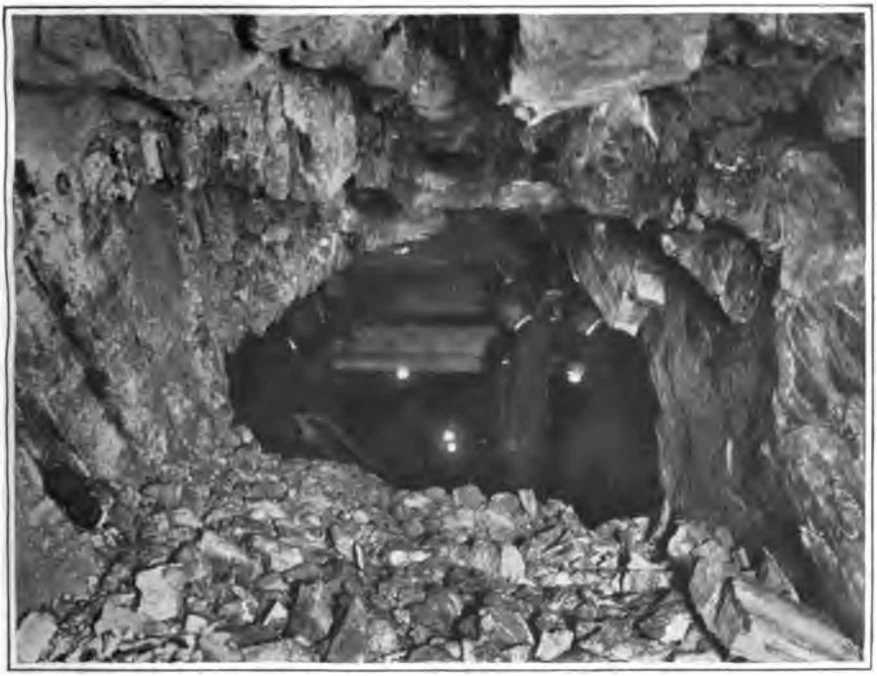
Arrived in Brooklyn, the aqueduct rises again to within two or three hundred feet of the surface and is pushed as far as it is possible to carry it in solid rock and yet communicate with the surface. This limit was found to be at the junction of Flatbush and Third Avenues.

Here it was necessary to go through 215 feet of overlying earth before coming to the rock. The caisson method had to be resorted to, and the caisson was sunk over 100 feet below the water line before rock was reached. Considerable difficulty was here experienced in sinking the shaft to the rock, because it called for the use of pneumatic pressure that taxed the endurance of the workmen to the limit. From here on the water will be conducted through pipes laid in a trench of a moderate depth below the surface. From the foot of Seventy-ninth Street, Bay Ridge, the conduit will be run across the Narrows to Staten Island, through a pipe 36 inches in diameter, provided with flexible joints, and laid in a submarine trench. The details of this section of the work have not yet been given out. However, tests have been made to discover at what depth the pipe line under the water must be buried. It is evident that it must lie far enough below ground to prevent its being entangled with anchors from large vessels that may have to anchor in the Narrows. The matter has been thoroughly investigated, and practical tests have been made by dragging anchors of large size along the bottom. It has been determined that if the pipe line is buried at least 8 feet under the bed, it will be entirely safe. On the Staten Island side a 48-inch pipe will carry the water on up the hill and through a tunnel into Silver Lake Reservoir, 120 miles from the source in the Catskills.

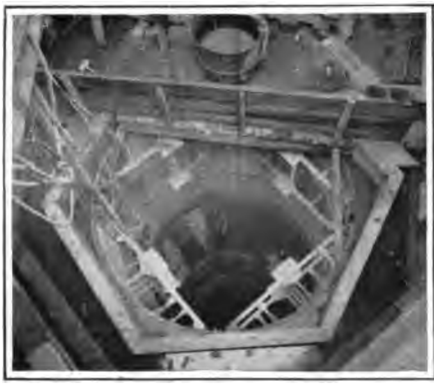
The greatest interest in this city section of the aqueduct attaches naturally to that part which is being excavated through solid rock under the busy city. It is a surprising fact that a work of such magnitude can be carried on directly under our feet without inconveniencing us in the least. The only surface evidence of the deep rock tunneling is to be found at the various shafts which are located in parks or public squares. The principal difficulty that presented itself at first was the question of storing explosives for a work of such great proportions. To keep the necessary explosives on the surface was to harbor constant menaces to the lives of the citizens. The matter was finally solved by placing the dynamite magazines far under the surface in the rock, and setting the doors to these magazines so they will automatically close in case of an explosion and trap the hot and poisonous fumes in the rock chamber, where they can do no harm to the workmen. The idea was borrowed from European practice, where mining operations are conducted close to and sometimes directly under large cities. Access to the dynamite chamber is had through a zigzag drift. At each turn of the drift a pocket is excavated, and the chamber itself is made of large capacity. In this chamber the dynamite is stored under a protecting roof to keep off any fragments of rocks that might fall when jarred by the "shooting" in the tunnel. At the entrance of the drift a very substantial concrete bulkhead is built, and in this is a low doorway. The door is



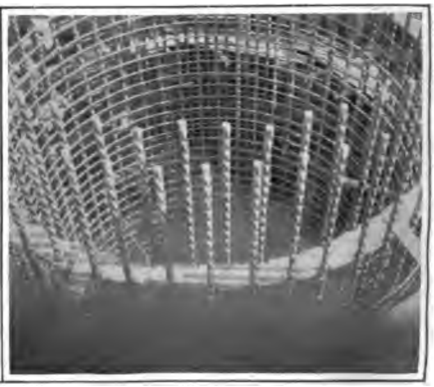
DRILL POSTS SET UP AT A TUNNEL HEADING, TWO DRILLS ON EACH POST.



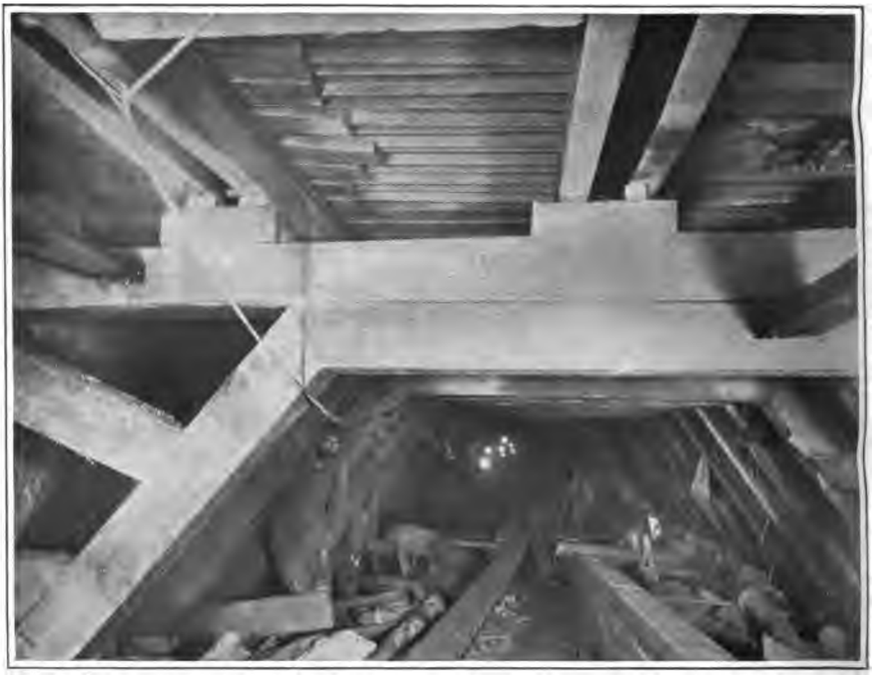
"HOLED THROUGH" FROM SHAFT 16 TO SHAFT 17. DANGEROUS ROCK OVERHEAD DUE TO VERTICAL SEAMS.



LOOKING DOWN THE 441-FOOT SHAFT AT ONE HUNDRED AND FORTY-NINTH STREET.



REINFORCEMENT FOR THE CAISSON AT FLATBUSH AND THIRD AVENUES.



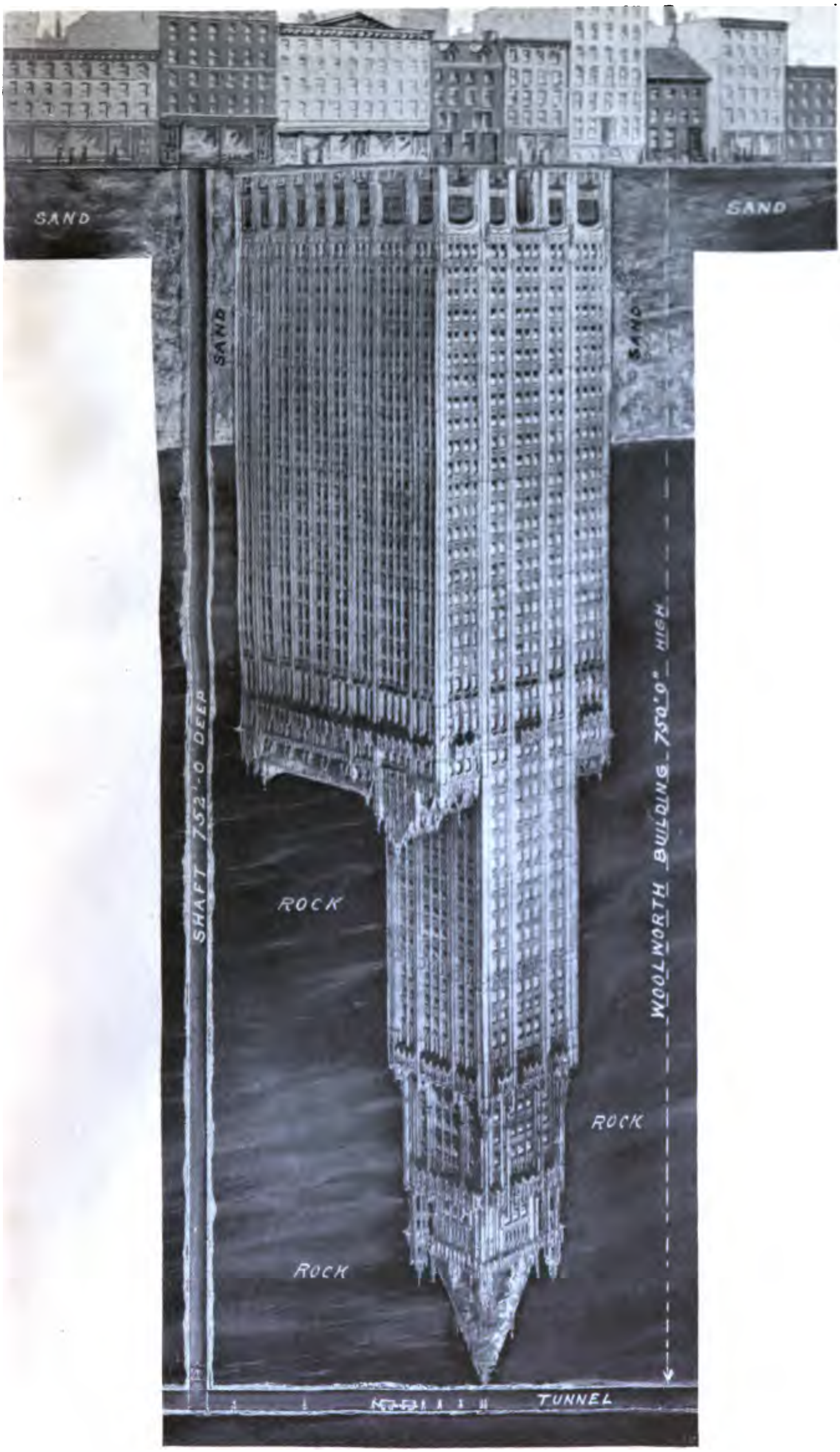
PERMANENT CHANNEL IRON SUPPORT FOR A TREACHEROUS ROOF. THE BEAMS WILL BE IMBEDDED IN THE CONCRETE LINING.

of massive construction, built of I-beams, 16 inches deep and spaced apart with oak beams 12 inches square. The door has beveled edges, so that it will seat itself snugly in the doorway. The door is always kept open at an angle of about 45°. In the magazine a thousand pounds of dynamite may be kept at a time. Should this be exploded, the explosion wave would have to travel down the zigzag passage and would lose much of its force at each abrupt turn, finally striking the door with greatly diminished energy. The door would be slammed shut by the blast of air issuing from the drift and would then be held shut by the gases of the exploded dynamite. A magazine of this sort has been constructed near the foot of each shaft—not *at* the foot, however, for fear that in case of a mishap, it might block the escape of the men. The magazines have been tested by exploding a number of sticks of dynamite around the first bend in the drift, and in every case the door has closed just as expected.

The work through the rock is being pushed very rapidly; at some of the shafts between 800 and 1,000 pounds of dynamite have been used daily. Within the last year millions of pounds of dynamite have been exploded under the city, while most of New York was totally oblivious to the fact. Already a number of the tunnel sections have been "holed" through. To expedite the work, one contractor is using an interesting form of shoveling machine, built especially for this work, so that it may be taken down the comparatively narrow shaft and be assembled to work within the small diameter of 11 feet, which is the size of the tunnel at the particular point where this machine is now being used. A photograph of this machine is shown herewith, and also a drawing illustrating the mechanism (pl. 10). The machine is controlled by a single operator and does the work of six laborers. It is provided with a double shovel *A* and *B*. The section *A* digs up the rock and throws it upon the scoop *B*, which in turn empties its load upon a traveling chain conveyor *C*; the latter delivers the load into muck cars at the back of the shoveling machine. The letters *B*, B^1, B^2, and B^3 show the successive positions of the scoop. The forward section *A* is carried upon a crank shaft *D*, which is revolved through the arc indicated by the arrow. Another arrow line shows the course of the front edge of the section *A*. The forward end of the scoop *B* rests upon the heel of the section *A*, while its rear end is mounted upon a shaft *E*, which travels in a guideway *F*. The forward section *A* is connected to the shaft *E* by means of side plates, indicated by dotted lines, so that as the crank shaft *D* revolves, the slide shaft *E* is obliged to run up the ways *F*, as indicated by the letters E^1, E^2, and E^3. The section *B* is equipped with a small arm *G*, which carries a roller that is adapted to engage the cam groove *H*, causing the scoop *B* to turn over as indicated in the dotted view B^3, and empty its load upon the traveling conveyor. The machine is mounted on a turntable so that it may be turned about in any direction.

Some of the work on the city pressure tunnel has been hurried so far that certain sections are now being lined with concrete. The forms used for this purpose are very interesting. Our illustration, plate 11, shows their construction. They cover 120 feet altogether and are arranged in two sections, 60 feet of the lower half of the tunnel being concreted in advance of 60 feet of the upper part. The first step is to lay the "invert;" that is, a narrow segment of the lining running along the bottom of the tunnel. This, when completed, forms the track upon which the forms for the rest of the lining travel. The forms are mounted on trucks with wheels tapered to fit the curve of the invert. The forms for the lower half cylinder are practically the same as those for the upper half cylinder. After the lining has set, the sides of the upper form may be drawn in to free them from the concrete by operating the turnbuckles *A*, and those of the lower forms by operating the turnbuckles *B*. Then jacks may be unscrewed to lower the upper section slightly, freeing it completely from the concrete, and jacks *E* may be screwed up to raise the bottom section slightly upon the truck. In this collapsed condition the forms may be drawn forward to complete the next section of tunnel. The detail view in the drawing (pl. 10, fig. 2) shows how the lower forms are supported on the trucks. To the longitudinal beams *C*, vertical guides *D* are bolted, which fit against the framework of the truck. The jacks *E* mounted on the truck bear against cross pieces running from *C* to *C*. The filling of the lower half of the forms is comparatively simple. It is quite a different task, however, to lay the concrete into the upper form. Sections of the plating of the upper forms are removed and the concrete is shoveled in, adding the plates step by step as necessary, until finally the topmost plate is added, when the concrete can be introduced only from the end of the form. It will be observed that small pieces of board are temporarily nailed against the edge of the forms and fitted up as neatly as possible against the rock above, so as to retain the concrete until it sets. As each section is completed, grouting holes are left in the top through which, when the lining is completed otherwise, grout will be forced under high pressure to fill up all cracks and crevices and make the lining perfectly sound.

At each shaft access will be had to the tunnel through risers or vertical pipes, 48 or 72 inches in diameter. At most of the shafts two such pipes will be provided, each fitted with valves at the bottom, which may be operated from the surface to close either of them when it is desired to gain access to them or to effect any necessary repairs. The valves at the bottom of the risers will be of such a design as to



HEIGHT OF WOOLWORTH BUILDING EQUALS DEPTH OF DEEPEST AQUEDUCT SHAFT IN NEW YORK.

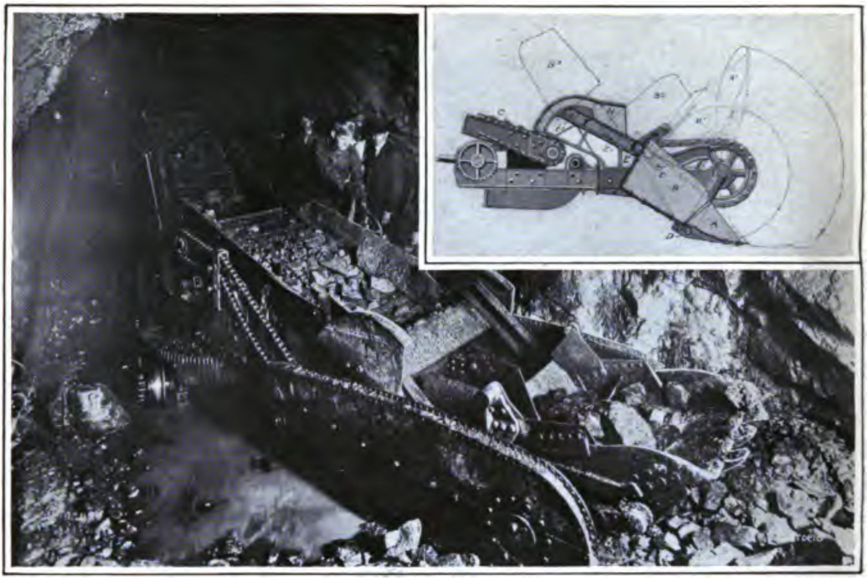


FIG. 1.—SHOVELING MACHINE FOR REMOVING THE BROKEN ROCK AND LOADING IT INTO CARS.

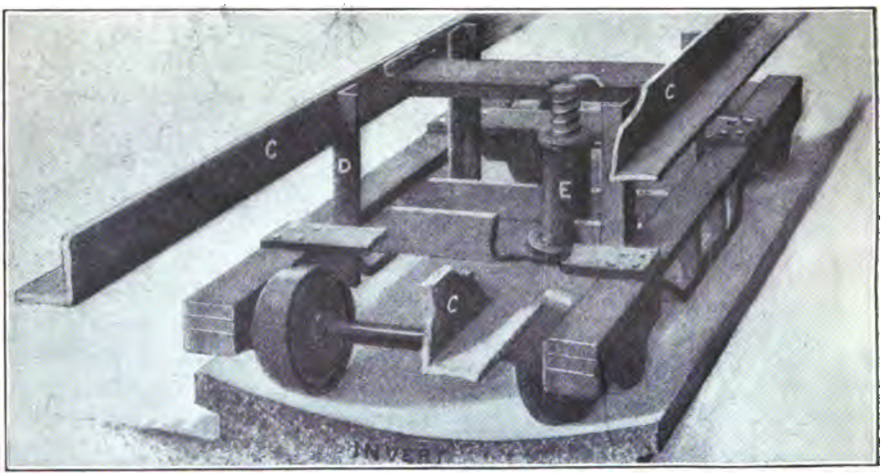
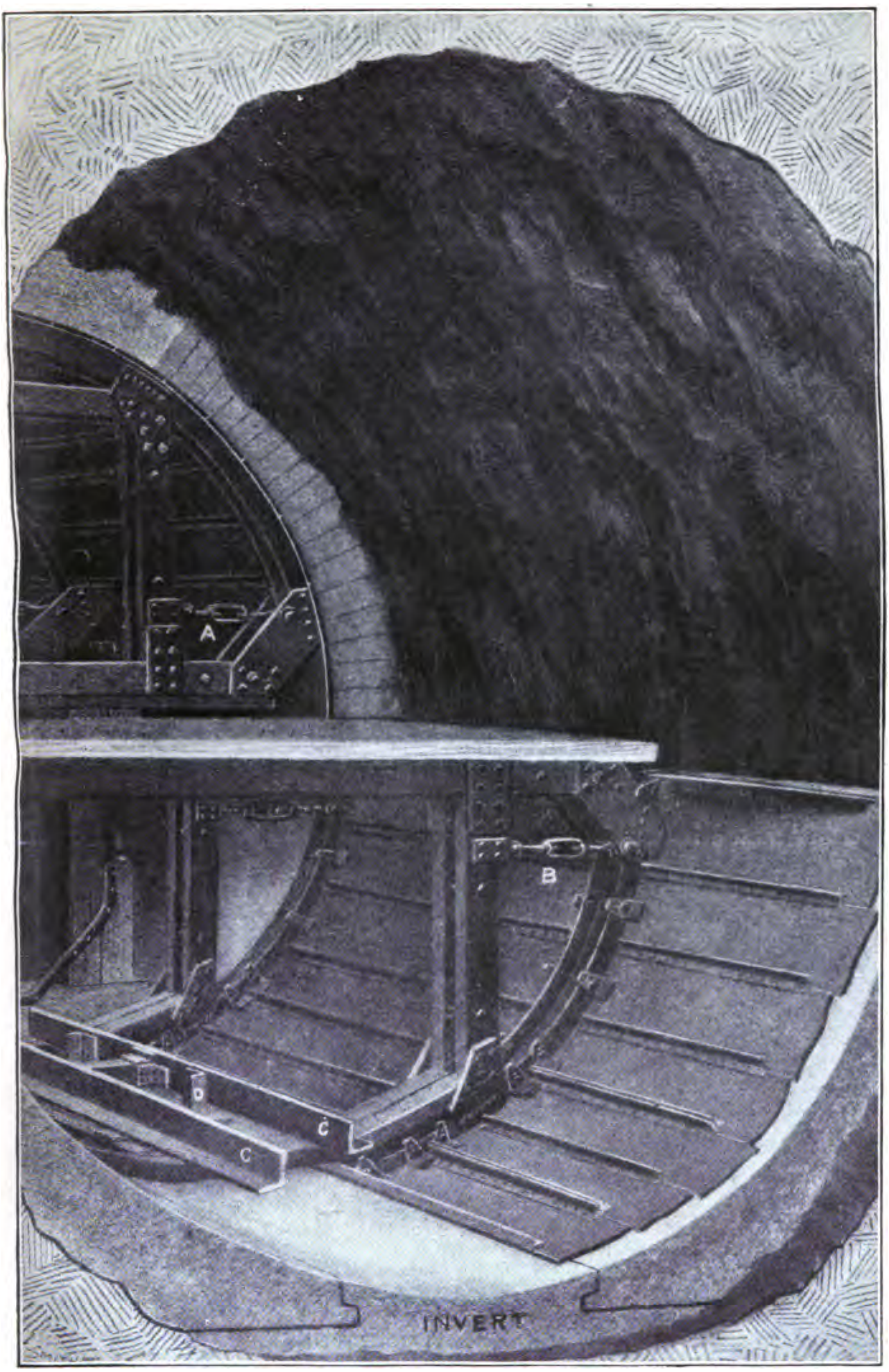


FIG. 2.—TRUCK FOR CARRYING STEEL FORMS FOR CONCRETE LINING.

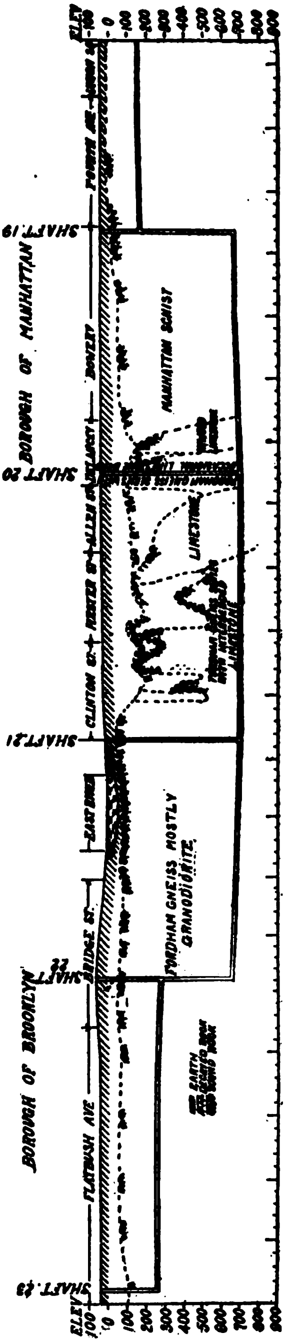


STEEL FORMS USED IN LINING THE AQUEDUCT WITH CONCRETE.

close automatically in case of an abnormal flow through the risers, due to the destruction of the valve at the top by explosion or other accident. At the top of the risers there will be two valves, the one nearer the riser being an emergency valve, which may be closed in case of any damage to the other valve.

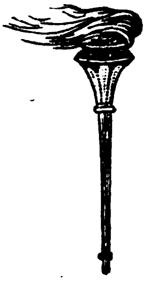
It is probable that no immediate changes will be made in the water supply of Manhattan and Bronx, except that pipe lines will be run from the shafts to help out the existing supply in case of emergency. In Brooklyn and Queens, where 35 pumping stations are now required, most of the stations will be discontinued for the reason that the water will be delivered through the aqueduct at sufficient pressure to reach practically all parts. Only in one or two sections will pumping be necessary.

From Hill View Reservoir the water will flow through a tunnel 15 feet in diameter. This will be narrowed to 14, 13, 12, and 11 feet, which is the diameter of the rock tunnel at Fort Greene Park, Brooklyn, and at the intersection of Flatbush and Third Avenues. From there on steel pipes, 5½ feet in diameter and running down to 4 feet in diameter, will carry the water to the Narrows, and under New York Bay, at the Narrows, the line will be only 3 feet in diameter. This gradual shrinking of the aqueduct reminds one of those large rivers that flow out of the mountains in sufficient volume to be navigable and even a menace to the surrounding country in time of flood, but which, when they reach the deserts, are drunk up by the thirsty sands and sucked by the torrid sun until they vanish without any clearly defined terminus or possibly flow in a sickly stream to a small stagnant lagoon. Thus, when the entire Catskill system is completed



Section along the city pressure tunnel, showing how it has to dip down under the pre-glacial bed of the East River.

and operating at its full capacity, the waters which three days before poured out of the Ashokan Reservoir in a mighty flood, over 17 feet in diameter, will reach Staten Island a stream only 3 per cent of its former size, after having been robbed by the rest of the thirsty city.



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